A PROPOSAL OF MUDA INDICATOR AGENT TO ESTIMATE LEAN MANUFACTURING VERIFICATION

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ABSTRACT: Lean Manufacturing (LM) is the philosophy to improve productivity of manufacturing system by eliminating wastes. LM tools have been implemented as software tools in order to implement this philosophy. However, implementing LM in factories does not always succeed because of several reasons; insufficient expertise and knowledge on LM practitioners, dynamic feature of complicated manufacturing processes, difficulty in quantifying the benefits of LM implementation, and etc. Simulation-based approaches have been proposed to support LM implementation, and their effectiveness has been reported in several papers. However, they are not suitable for LM practitioners who are not familiar with simulation software. Therefore, some appropriate niche techniques to bridge the gap between LM practitioners and simulation-based approaches are expected to achieve successful LM implementation. This research proposes an agent-based approach to

LM implementation using Muda Indicator (MI) agent to narrow the gap. This paper presents the overview of MI agent, defines quartile calculation to determine Muda level, explains MI indication by MI agent, and shows the feasibility of MI agent using a manufacturing process model. The feasibility study showed how MI agent presents transition of quantifying wastes during simulation in a dynamic manner.

KEYWORDS: *Lean Manufacturing, Quantifying Waste, Manufacturing Simulation, Intelligent Agent*

1.0 INTRODUCTION

To be competitive in the global market today, continuous improvement of productivity in manufacturing system without lowering its quality level is required not only to large companies but also small and medium companies [1]. Lean manufacturing (LM) is one of the key techniques to comply with this requirement [2-4]. The goal of LM is to identify wastes throughout entire value stream of production system and to eliminate these wastes [5]. Elimination of wastes is one of the most effective ways to increase the profitability in production system. In LM system, any activity in production process that does not add value is regarded as wastes, which is often called "Muda" in LM term [6]. As for typical wastes which are required to be eliminated to improve profitability, Toyota Production System points out seven basic wastes or seven Muda; M1: "Transportation: Unneeded product movements in performing certain processes"; M2: "Inventory: Raw materials which are not being processed";M3: "Motion Unnecessary movement of people or equipment to perform the processing; M4: Waiting (delay) : Inactive people, processes or Work-In-Progress while waiting for the next production step; M5: "Overproduction : Producing items before they are actually needed;M6: Over-processing: Unneeded steps in processes resulting from poor tool or product design; M7 : Defects : Producing defective products due to poor preventive quality system.

To achieve LM philosophy and to eliminate these seven wastes, typical LM principles are already established as LM tools, such as single minute exchange of die (SMED), Kanban, preventive maintenance, cellular manufacturing and others. Some of these LM tools are also implemented as software tools to support waste elimination.

However, implementation of LM does not always succeed even if some of these LM tools are applied [7-9]. One of the biggest obstacles in successful implementation is lack of expertise in selection of appropriate

LM tool for each specific situation. Another reason is lack of extensive knowledge and experience which are required to implement LM tools [9-10]. Furthermore, LM tools are basically applied in a deterministic way based on analysis of a static model, which is not always applicable to real production system which is dynamic [11]. Difficulty in quantifying benefits expected by LM implementation is another issue which makes it hard to convince management team in applying LM tools [12-13]. Because of these reasons, implementation of LM does not always work.

Simulation-based approaches are proposed to solve these implementation issues in LM. However, there is a draw backs associated with simulation based approaches are suitable for simulation engineers who know how to design/build/analyze the simulation model, and how to integrate it to LM software [14]. They are not suitable for LM practitioners who are not familiar with simulation software, nor LM tool software. Therefore, some appropriate niche techniques to bridge the gap between LM practitioners and simulation-based approaches are expected to achieve successful LM implementation.

This research proposes an agent-based approach to LM implementation, where an intelligent agent called "Muda Indicator" (MI) agent plays a critical role to support LM practitioners for their decision making and selection of LM tools. MI agent continuously reviews the Muda level during simulation and show the status with three different colors (R: Red; A: Amber; G: Green). Using a manufacturing process model of coolant hose manufacturing (CHM) company, feasibility of MI agent was studied.

2.0 RESEARCH BACKGROUND

This research focuses on agent-based technology to propose a solution to the above mentioned gap issue. An intelligent agent is a computer system that is designed to execute flexible autonomous actions to accomplish tasks on behalf of its user [15]. Intelligent agent is expected to solve problem that already can be solved in a significantly better way[16]. Moreover, intelligent agent by its nature is active (means adding value), autonomous and modularized (means having a human-like behavior) [17]. Nowadays, intelligent agent are widely applied in industries such as in process control (e.g. Architecture for Cooperative Heterogeneous On-line system (ARCHON)), manufacturing (e.g. Yet Another Manufacturing System (YAMS)), air traffic control (e.g. Optimal Aircraft Sequencing using Intelligent Scheduling (OASIS)), financial (e.g. Fin CEN Artificial Intelligence System) [18].

Jahangirian et al. [19] carried out extensive review of 281 peer-reviewed papers between 1997 and 2006 and found out that intelligent agent system (IAS) is the fourth most popular simulation technique (usage rate more than 5%) used to solve problem in manufacturing. IAS is preferred due to its capability to design manufacturing systems that is flexible to accommodate dynamic nature of manufacturing processes [20].

This research proposes an intelligent agent called MI agent to support LM practitioners for their decision making in LM tool selection and its application. Using a manufacturing process model of coolant hose manufacturing (CHM) company, MI agent was implemented and its feasibility was studied.

3.0 MUDA INDICATOR (MI) AGENT

3.1 Overview of MI Agent

Typically, simulation study in lean projects is usually results are managed by simulation engineers. Therefore, real time updating of simulation model can only be performed by simulation engineers [21]. Usually, results are obtained at the end of simulation runs. Misunderstanding between domain experts and simulation engineers may lead to development of a biased simulation model [22].

As opposed to agent-based approach, MI agent continuously monitors status of wastes quantitatively and learns them during simulation runs. MI agent reviews the results of waste in terms of RAG (Red; Amber; Green) status and presents them by Muda level at any time during simulation. Since MI agent is designed to be an independent application, it could be placed freely in the application. Effectiveness of communication between domain experts and simulation engineers is also enhanced by interaction with MI agent as shown in Figure. 1.

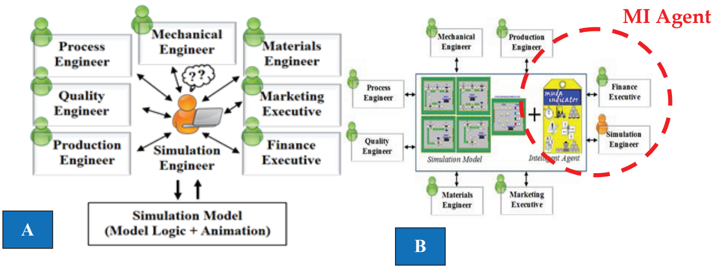


Figure 1: Comparison between traditional simulation approach (Picture A) and agent-based approach (Picture B)

3.2 Development of MI Agent

MI agent was developed in the following three steps. Step 1 of MI agent development was collection of observation data. Step 2 is performance level (PL) calculation of each Workstation(WS) in manufacturing line using mathematical calculation. Step 3 is Muda level determination by quartile calculation method. Muda level is the status of waste in a manufacturing line. To determine Muda level, distribution pattern of Performance Level(PL) was assessed by using quartile calculation to attain Q1, Q2 and Q3 of each WS.

A set of data from each WS is arranged in ascending order of magnitude *X (1), X (2)…, X (n)* as shown in Figure 2. The median (middle value of the data set) is determined followed by calculation of each quartile. Quartile calculation is executed for even and odd sample size *(n)* accordingly.

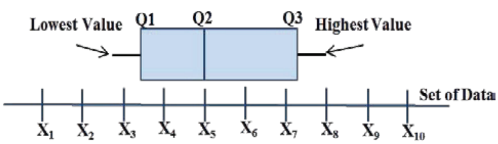


Figure 2: Quartile range [4, 23]

For even sample size (n),

Q1 (First quartile) = median of $x_{(1)},\ldots\ldots,x_{(n/2)}$ (1)

Q2 (Second quartile) = $[x_{(n/2)} + x_{\left(\frac{n}{2}+1\right)}]/2$ (2)

Q3 (Third quartile) = median of $x_{\left(\frac{n}{2}+1\right)},\ldots\ldots,x_{(n)}$ (3)

For odd sample size (n),

Q1 (First quartile) = median of $x_{(1)},\ldots\ldots,x_{\left(\frac{(n+1)}{2}-1\right)}$ (4)

Q2 (Second quartile) = $x_{((n+1)/2))}$ (5)

Q3 (Third quartile) = median of $x_{\left(\frac{n+1}{2}+1\right)},\ldots\ldots,x_n$ (6)

After Q1, Q2 and Q3 were determined, Muda level was set depending on the condition of the manufacturing line.

3.3 MI Agent: How It Works

MI agent is designed to be placed on a manufacturing simulation model. During simulation runs, MI agent continuously monitors status of waste (Muda level) and learns them in a semi-autonomous way. Muda level is presented in the form of graphical image of RAG status. A green status indicates that Muda is not present. Amber status indicates that Muda exists but still within acceptable limits and warrants attention. Red status indicates that Muda is beyond the acceptable limits. Table 1 exemplifies two conditions of waste in manufacturing line in relation to Muda level.

Table 1: Muda level for different conditions of waste

Muda Level	Condition A	Condition B
R (Red)	PL ≤ Q1	PL ≥ Q3
A (Amber)	Q1 < PL < Q3	Q1 < PL < Q3
G (Green)	PL ≥ Q3	PL ≤ Q1

4.0 FEASIBILITY STUDY OF MI AGENT IN COOLANT HOSE MANUFACTURING (CHM) FACTORY MODEL

4.1 Customization of MI Agent in CHM Factory Model

In this study, MI agent implementation was shown by using a process model of CHM factory (Figure 3). The process model of CHM factory was developed using simulation software (Rockwell Arena 12.0). CHM factory produces four types of coolant hose products, which are called CH4, CH6, CH8 and CH10. The factory floor is divided into six sections from Section 1(S1) to Section 6(S6). S1 is the supplier section, which supplies raw materials to S2, S3, S4, and S5. Then, S2, S3, S4 and S5 supply their processed parts to S3/S4, S4, S5 and S6, respectively. Detail explanation on development, verification and validation of CHM factory for simulation model can be obtained from [4, 23].

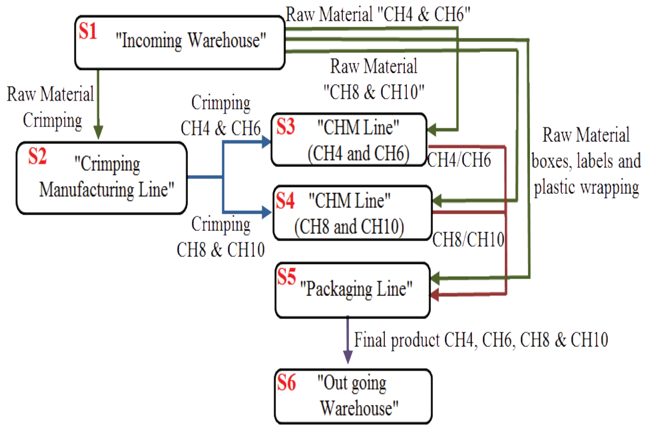


Figure 3: Process model of CHM factory floor [4, 23]

In this study, customization of MI in CHM factory simulation model is shown using S4 as an example of S4 in Figure 4. S4 consists of 6 WSs and produces two types of products, CH8 and CH10. Changeover (C/O) process occurs at WS1 and WS6. Waiting Muda, or M4, was chosen to show how MI agent works in simulation. In the case, waiting Muda was defined as an idle status of operator due to starvation of parts/ materials, which causes high C/O task time in WSs (Table 2).

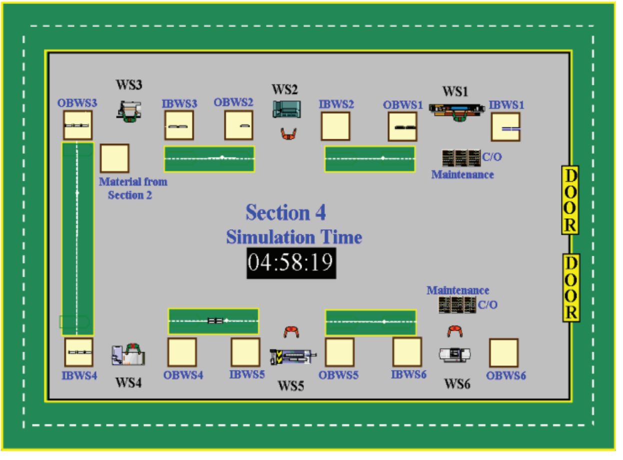
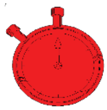


Figure 4: Snapshot of S4 simulation model [4, 23]

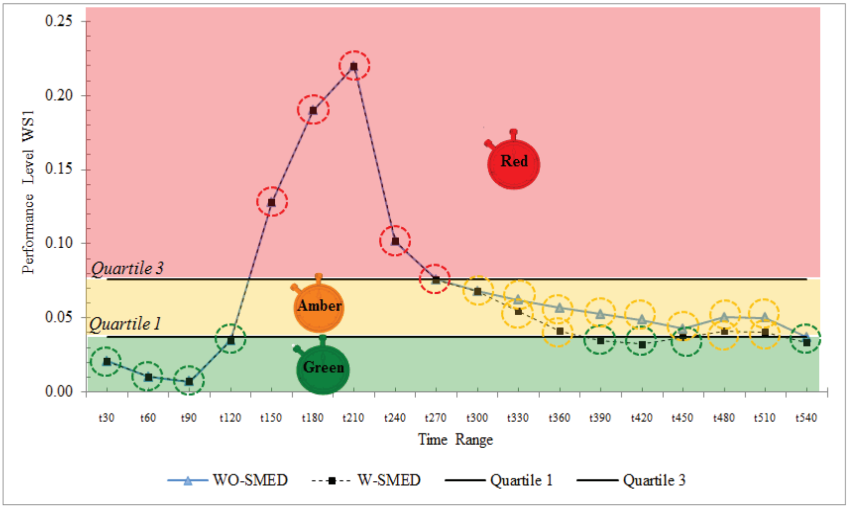
Table 2: Definition of Muda level in "Waiting"

Muda level with "R.A.G status" indicator	*Definition of Muda level in "Waiting"*
 **Red**	*Red status indicates that Muda (prolonged idle status of operator) is beyond the acceptable limits.*
 **Amber**	*Amber status indicates that Muda (prolonged idle status of operator) exists but is still within acceptable limits and warrants attention.*
 **Green**	*Green status indicates that Muda (prolonged idle status of operator) is not present.*

4.2 Feasibility Study of MI Agent in CHM Factory Model

SMED LM tool was implemented in WS1 of S4 and the customized MI agent was incorporated into WS1 simulation model. The performance levels of WS1 with and without SMED implementation were shown in Table 3 and Figure 5.

MI agent semi-autonomously coped with the dynamic nature of manufacturing process in WS1 and updated the performance level during simulation from t30 to t540. Figure 5 shows that MI agent did not reveal any difference in PL values from t30 to t300. This is because no C/O process took place in WS1 from the time t30 to t300. However, MI agent showed significant decrement of PL value from amber to green at the time t390 when SMED was implemented and the green color continued until the time t450. This behavior of MI indicates that MI agent autonomously detected the process improvement by SMED LM tool and proved that the process improvement was successfully achieved.



W-SMED (with SMED); WO-SMED (without SMED)
Figure 5: Performance level of WS1 W-SMED and WO-SMED

Table 3 showed the quantitative results of PL calculated by MI agent. This quantitative information on the percentage of PL improvement was designed to provide pro-active assistance to LM practitioner so that selection of LM tool could be appropriately achieved.

Table 3: PL improvement of WS1 W-SMED and WO-SMED

Time Range			t_{30}	t_{60}	t_{90}	t_{120}	t_{150}	t_{180}	t_{210}	t_{240}	t_{270}
WS1	PL	WO-SMED	0.0207	0.0103	0.0069	0.0348	0.1279	0.1899	0.2199	0.1015	0.0757
		W-SMED	0.0207	0.0103	0.0069	0.0348	0.1279	0.1899	0.2199	0.1015	0.0757
	Improvement	(%)	0%	0%	0%	0%	0%	0%	0%	0%	0%
Time Range			t_{300}	t_{330}	t_{360}	t_{390}	t_{420}	t_{450}	t_{480}	t_{510}	t_{540}
WS1	PL	WO-SMED	0.0681	0.0619	0.0568	0.0524	0.0487	0.0426	0.0502	0.0500	0.0370
		W-SMED	0.0681	0.0543	0.0410	0.0349	0.0322	0.0370	0.0412	0.0401	0.0334
	Improvement	(%)	0%	12%	28%	33%	34%	13%	18%	20%	10%

5.0 CONCLUSION

This research proposed an agent-based approach to LM implementation, where MI agent plays a critical role to support LM practitioners for their decision making and selection of LM tools. MI agent continuously reviews the Muda level during simulation and show the status by RAG with three different colors. Using a manufacturing process model of coolant hose manufacturing (CHM) company, feasibility of MI agent was studied. The feasibility study showed that MI agent handled the dynamic nature of manufacturing processes in a semi-autonomous way and pro-actively provided RAG status during simulation. MI agent also showed transition of quantifying wastes during simulation in a dynamic manner.

Future work includes implementation of full-autonomous capability of MI agent, enhancement of MI agent function to cover the remaining types of Muda in manufacturing processes, design/implementation of various manufacturing processes to apply MI agent for further feasibility study, usability experiments to evaluate MI agent, web-based implementation of MI agent to apply for practical use, and etc.

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